IMPLICATIONS FOR THE STRUCTURAL INTEGRITY OF THE VENUSIAN CRUST

Final Report for the Appointment as
Visiting Graduate Fellow, Summer 1980

of

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Abstract

Comparisons of the fracture and yield stresses for the lithospheres of the Earth and Venus are derived from known empirical fracture and flow laws.

Introduction

At the last Lunar and Planetary Science Conference (XI, March 1980), two models were presented for the present state of the crust of Venus. In order to explain the ^{40}Ar deficiency in the venusian atmosphere, H. Spetzler and D. Dunham (1) proposed a thin, "plastic," lithosphere (~25 km) in which topographic features are supported dynamically by deeper convection. Their model is derived from considerations of planetary outgassing and conditions that would inhibit release of volatiles within the last three billion years on Venus. The immediate assumption takes the form of having the greenhouse effect on Venus raise the temperatures and pressures on the planet to a point where the surface acts totally ductilly to "plastically seal off" further outgassing within later history of Venus. Conversely, while trying to explain the lack of observed tectonic features (subduction trenches or mid-ocean type rift-ridge systems) on the surface as seen by radar altimetry, R. J. Phillips *et al.* (2) concluded that the crust is dry, rigid, and thicker than that of the Earth. Using the argument that lack of H_2O is a strong deterent to plate tectonics, they concluded that Venus is a one plate planet in which most of the topography is passively supported by a thick crust. Verification of their ideas resulted from analyses of the radar images. Both concepts attempted to extend on the ideas of Weertman (3) concerning the creep properties of various rocks at Venusian conditions.

The purpose of my appointment as Visiting Graduate Fellow during the summer of 1980 was to resolve this disagreement. The primary objective was to fit known empirical laws concerning the response of likely venusian rocks to venusian conditions in order to determine the structural integrity of the venusian crust. Rather than make absolute judgment of the results, corresponding curves for the Earth were to be also derived. Although useful curves were found, the resulting set is not complete enough to make a valid conclusion; however, the set may provide a significant contribution to obtaining such a conclusion when extended.

VENUS VERSUS THE EARTH

The surface of Venus is hotter and under more pressure than that of the Earth. The Venera 8, 9, and 10 landers determined the following properties for Venus (4):

temperature (T_o)	≈ 740°K
pressure (P_o)	≈ 90 atm
surface rocks	≈ basaltic (and possibly granitic)
surface density (rocks) (P)	≈ 2.7 ~ 2.9 g/cc

Global values of these parameters vary little from the values listed as a result of the greenhouse effect of the venusian clouds. In contrast the Earth has the following properties:

temperature (T_o)	≈ 300 - 350°K (mean)
pressure (P_o)	≈ 2 atm
crustal rocks	≈ basaltic and granitic
(ignoring sedimentary veneer)	

In subsequent calculations, a surface temperature of 350°K for the Earth is used.

Concerning variation of parameters with depth the following assumptions were made:

A) Density (P) is constant at 3.0 g/cc for both Venus and Earth (as is gravity)

B) Pressure (P) has the form:

$$P = P_o + \rho g z$$

C) Two versions of temperature (T) were used:

1) $T = T_o + (\Delta T)Z$

where ΔT = 5 or 10 K/km

2) $T = T_o + 1579\ (1 - \exp(-7.6 \times 10^{-3}\ \mathrm{km} \times Z))$

(after Ashby and Verrall (6))

D) Surface constants:

Venus T_o = 740°K

P_o = 90 atm

g = 981.0 cm sec^{-2}

Earth T_o = 350°K

P_o = 1 atm

g = 887.4 cm sec^{-2}

FLOW AND FRACTURE LAWS USED

A) Fracture of Basalt:

The curve for basalt fracture is derived from the fracture criterion of Lindholm *et al.* (5) for Dresser basalt:

$$\frac{\sigma_1}{S_c(0)} + \frac{S_c(0) - S_{BC}(0)}{S_c(0)S_{BC}(0)}\ \sigma_2 + \frac{\sigma_3}{S_T(0)} = 1 - \beta T\ (A - \log \dot{\varepsilon})$$

where $S_c(0) = 1.25 \times 10^5$ psi

$S_T(0) = 4.687 \times 10^4$ psi

$S_{BC}(0) = 1.5625 \times 10^5$ psi

$\beta = 2.21 \times 10^{-4}\ K^{-1} = R/(U_o + \nu\sigma_o)$

$A = \log \dot{\varepsilon}_o$

combined with:

$$\dot{\varepsilon} = \dot{\varepsilon}_0 \exp\left(-\frac{U}{RT}\right)$$

where

$$U = U_0 - \nu(\sigma - \sigma_0)$$

where $\nu = 3.15 \times 10^{-23}$ cm^3

to get:

$$\frac{\sigma_1}{S_c(0)} + \frac{S_c(0) - S_{BC}(0)}{S_c(0)S_{BC}(0)} \sigma_2 + \frac{\sigma_2}{ST(0)} = \frac{B}{R} \nu\sigma$$

where $\sigma \equiv$ stress difference

$= \sigma_1 - \sigma_3$

letting

$$D\sigma + HP = \frac{\sigma_1}{S_c(0)} + \frac{S_c(0) - S_{BC}(0)}{S_c(0)S_{BC}(0)} \sigma_2 + \frac{\sigma_3}{S_T(0)}$$

$$D\sigma + HP = \frac{B}{R} \nu\sigma$$

or

$$\sigma = \frac{RHP}{(B\nu - RD)}$$

For compression:

$$\sigma_3 = P$$

$$\sigma_2 = P + a\sigma \qquad 0 \le a \le 1$$

$$\sigma_1 = P + \sigma$$

$$D = \frac{1}{S_C(0)} + a\left(\frac{SC(0) - S_{BC}(0)}{S_C(0)S_{BC}(0)}\right)$$

$$H = \frac{1}{S_C(0)} + \frac{S_C(0) - S_{BC}(0)}{S_C(0)S_{BC}(0)} - \frac{1}{S_T(0)}$$

For tension:

$$\alpha_3 = P - \sigma$$

$$\alpha_2 = P - a\sigma \qquad 0 \leq a \leq 1$$

$$\alpha_1 = P$$

$$D = \frac{1}{S_T(0)} - a\left(\frac{S_C(0) - S_{BC}(0)}{S_C(0)S_{BC}(0)}\right)$$

$$H = \frac{1}{S_C(0)} + \frac{S_C(0) - S_{BC}(0)}{S_C(0)S_{BC}(0)} - \frac{1}{S_T(0)}$$

In the calculations performed $a = 0, 0.5,$ and 1.

B) Fracture of Olivine:

The curve for olivine fracture is adopted from Ashby and Verrall (6):

For tension:

$$\text{if } P < \sigma_f \quad \text{then } \sigma = 2\,(\sigma_f + P)$$

$$P \geq \sigma_f \quad \text{then } \sigma = 4\,(\sigma_f P)^{1/2}$$

where

$$\sigma_f = 5 \times 10^{-3}\,[8.13 \times 10^5 \left(1\text{-}0.35\,(\tfrac{T-300}{Tm})\right) + 1.8\,(p\text{-}P_1)]\ \text{bar}$$

where $P_1 = 1$ atm

Compression fracture is defined as 8 times tension fracture after Ashby and Verrall.

C) Quartz Yield:

The curve for quartz yield is that of Griggs (7) and for T > 300°C.

$$\sigma_y = 0.44 \exp\left(\frac{4570}{T}\right) \text{bar}$$

D) Creep — Equivalent Strain Rates:

The creep equation of Weertman (3) is used to determine equivalent strain rates:

$$\bar{\varepsilon} = C\sigma^n \exp(-Q/RT)$$

For olivine the coefficients of Kohlstedt and Goetze (8) are used:

$C = 4.2 \times 10^{11}$ Kbar^{-n} sec^{-1}

$Q = 125$ Kcal/mole

$n = 3.0$

For basalt the enstatite coefficients of Ross and Nielsen (9):

$C = 2.32 \times 10^{3}$ Kbar^{-n} sec^{-1}

$Q = 64.8$ Kcal/mole

$n = 2.8$

RESULTS AND OBSERVATIONS

Included are the graphs of the various models calculated. As noted previously, these curves do not provide a basis for making a valid conclusion. Curves for the yield of basalt and/or olivine are needed for such a result. However, if one assumes that either curve is similar to the quartz yield curve, one finds ductile behavior near the surface for Venus in contrast to below 10 km depth for the Earth.

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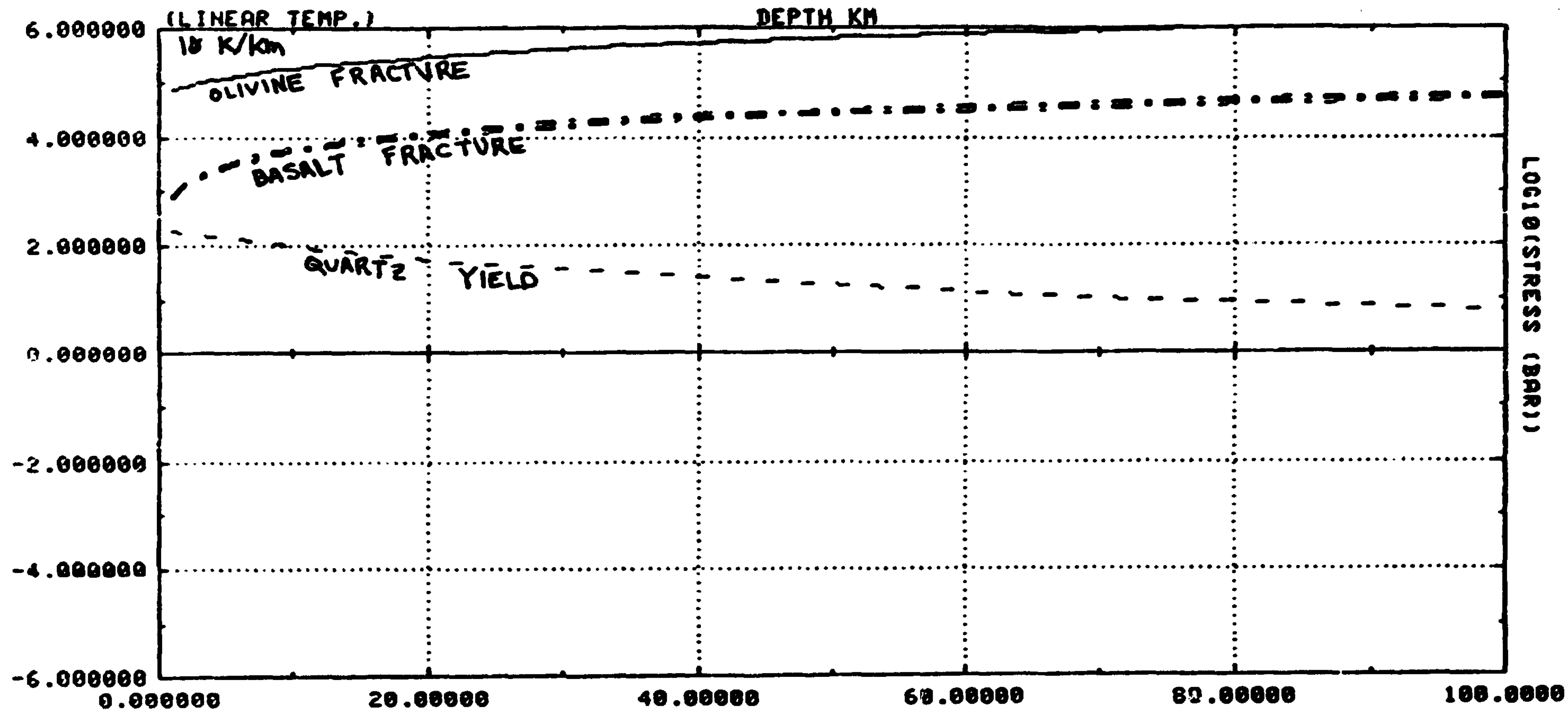

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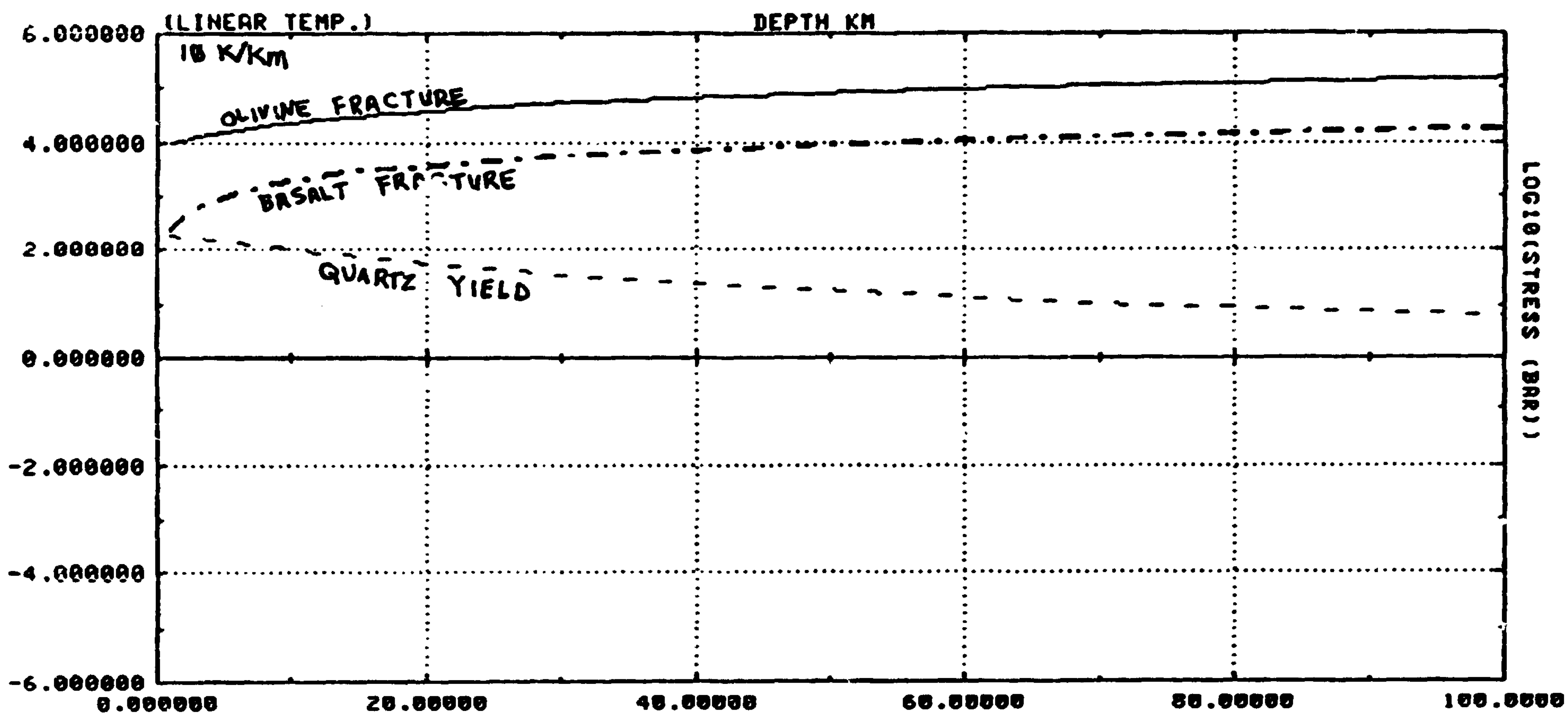

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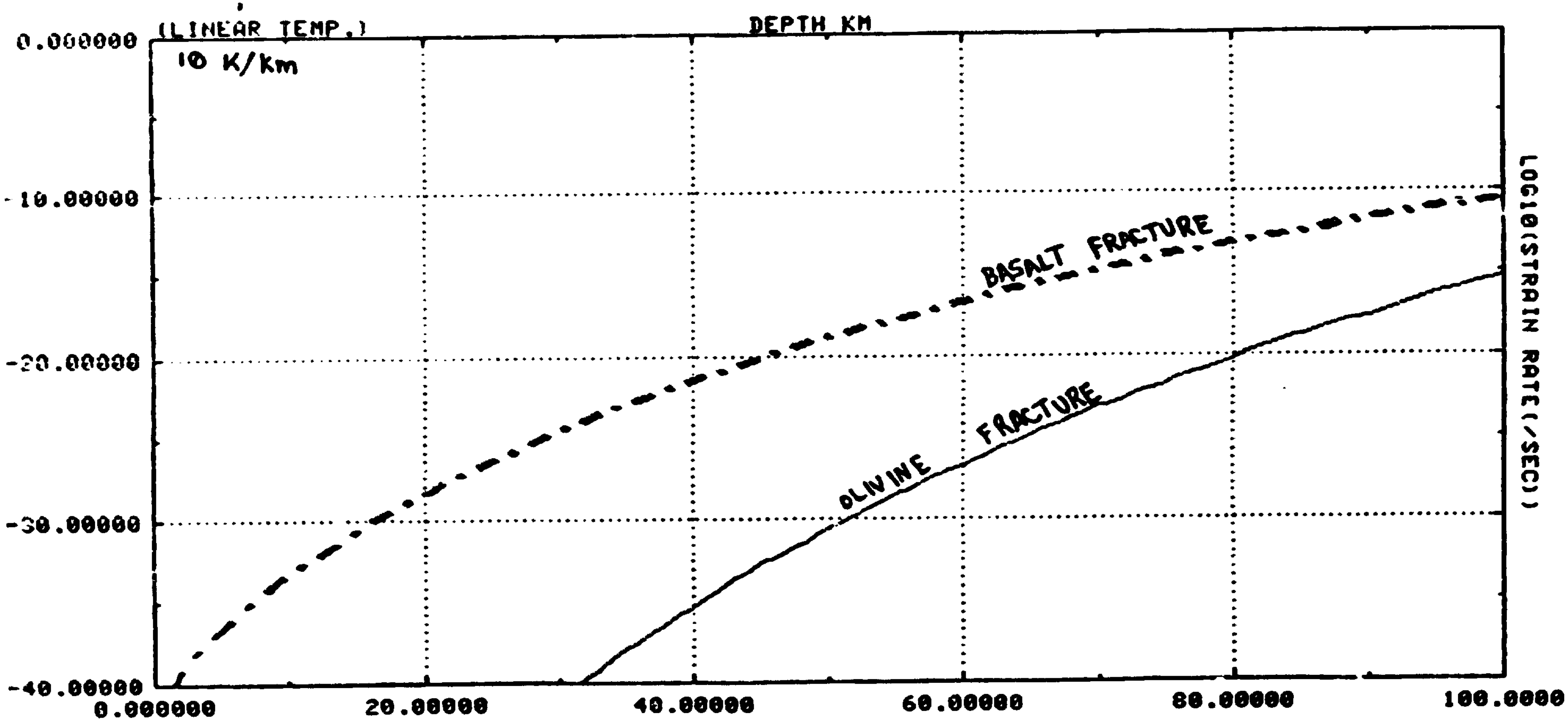

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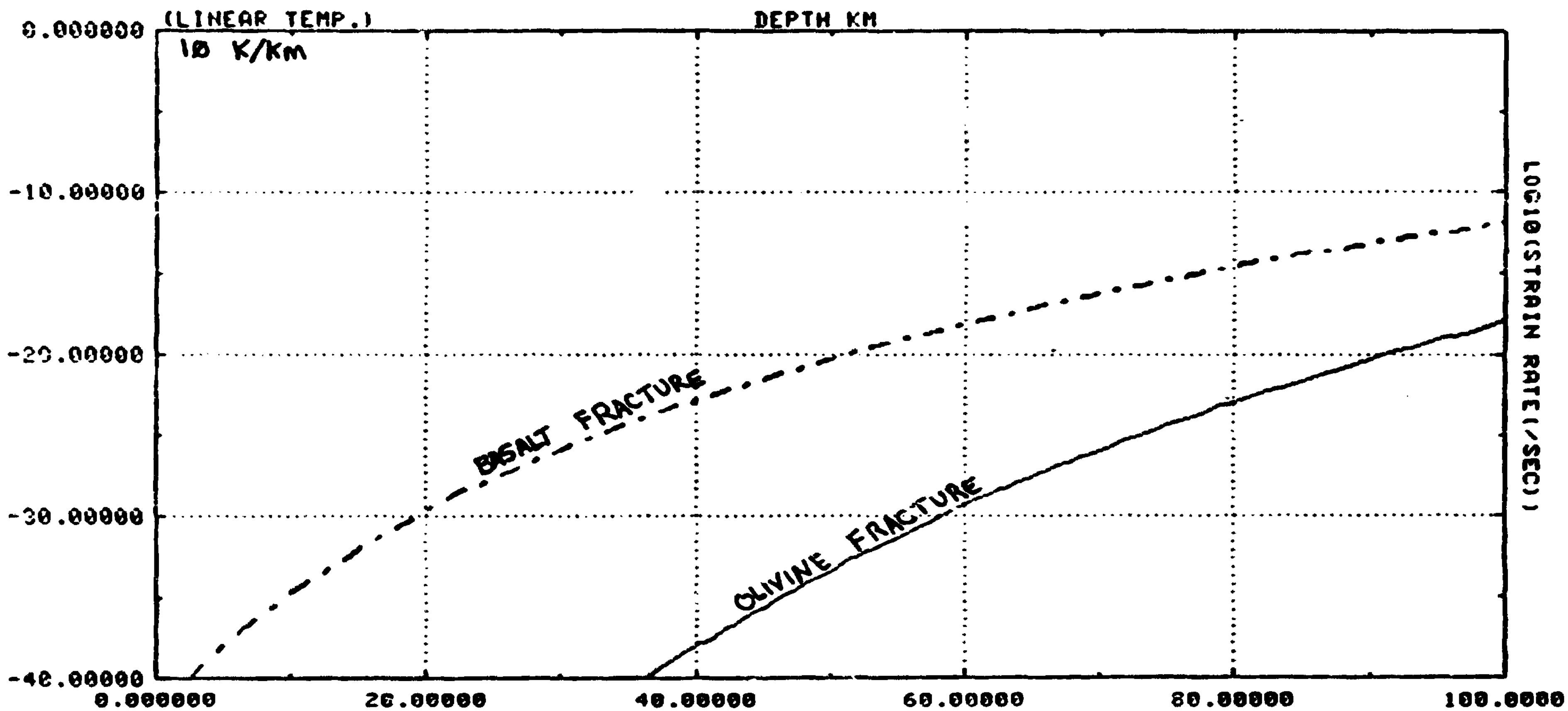

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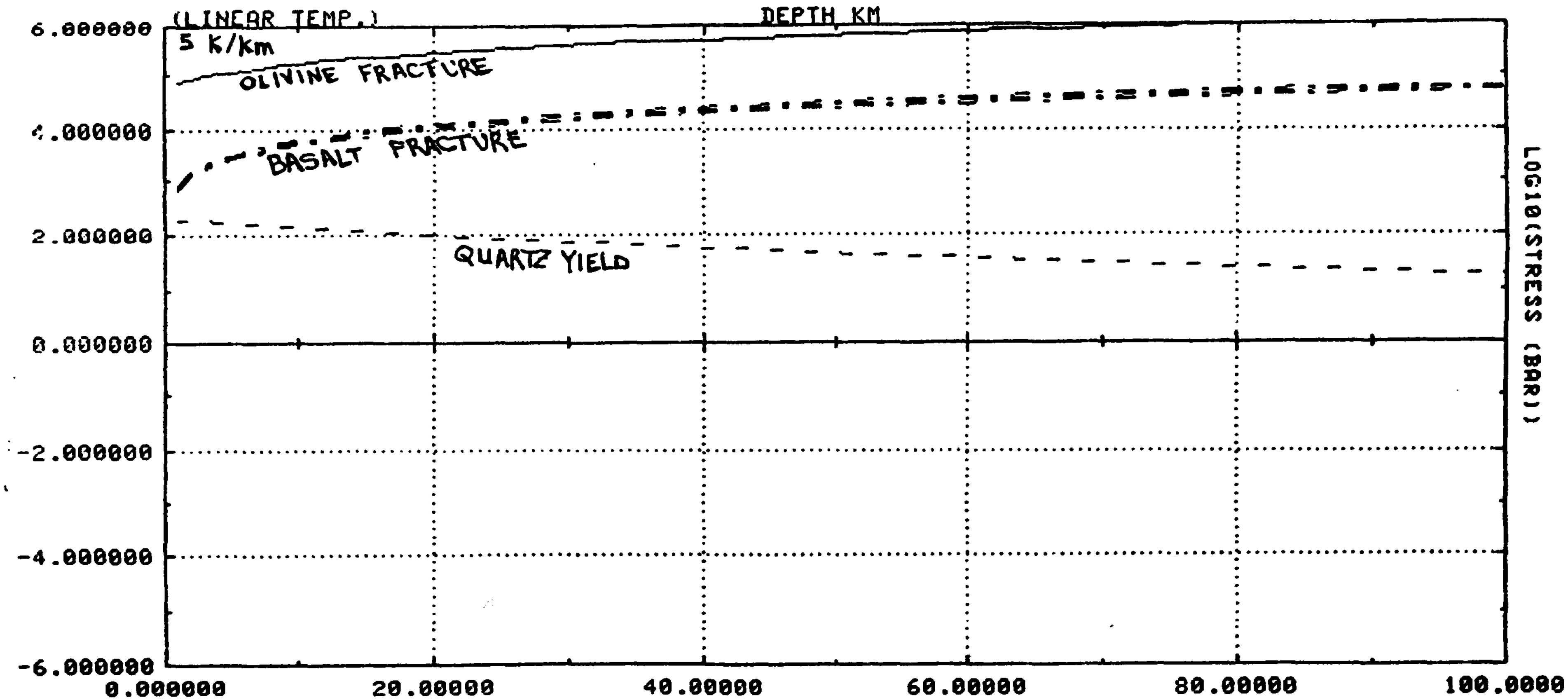

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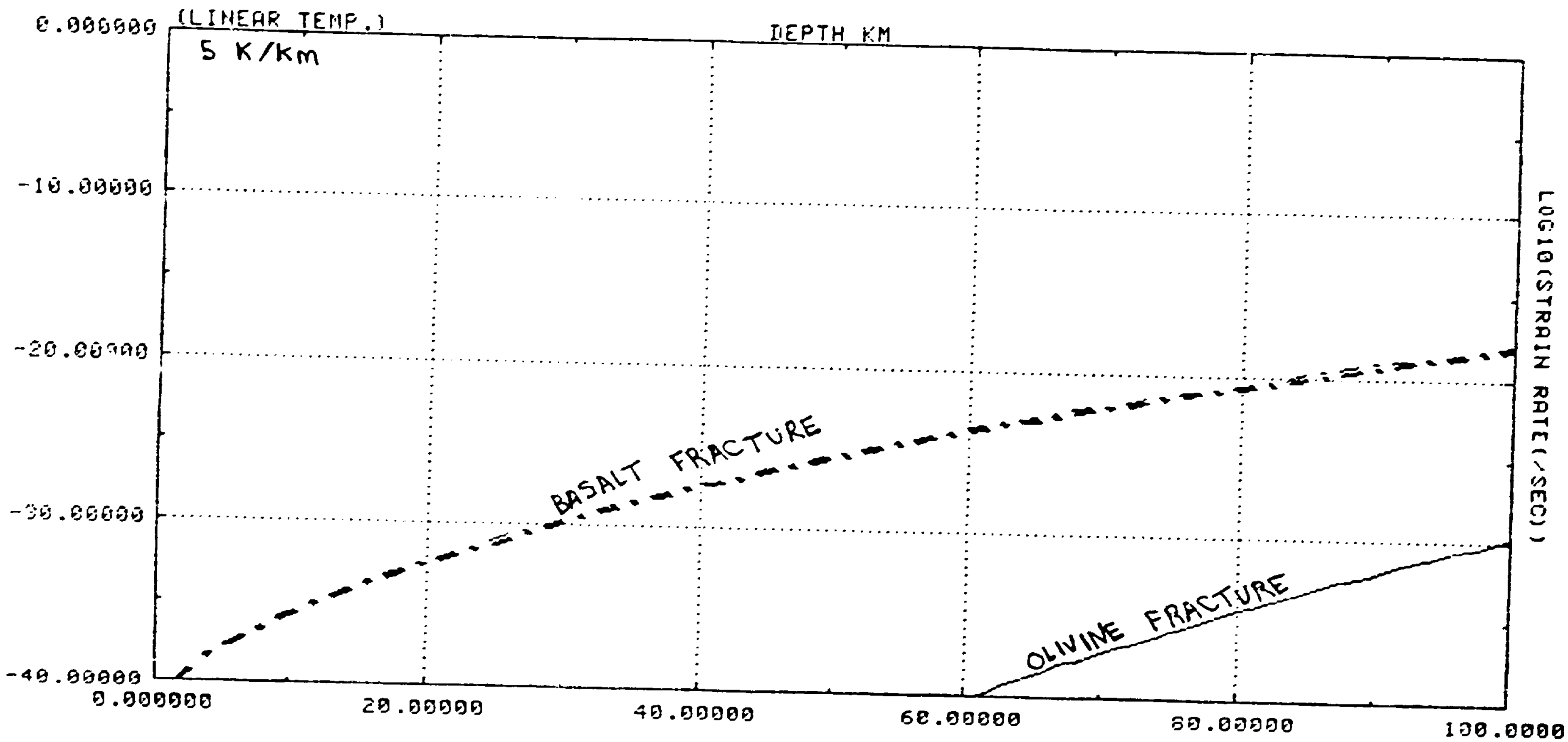

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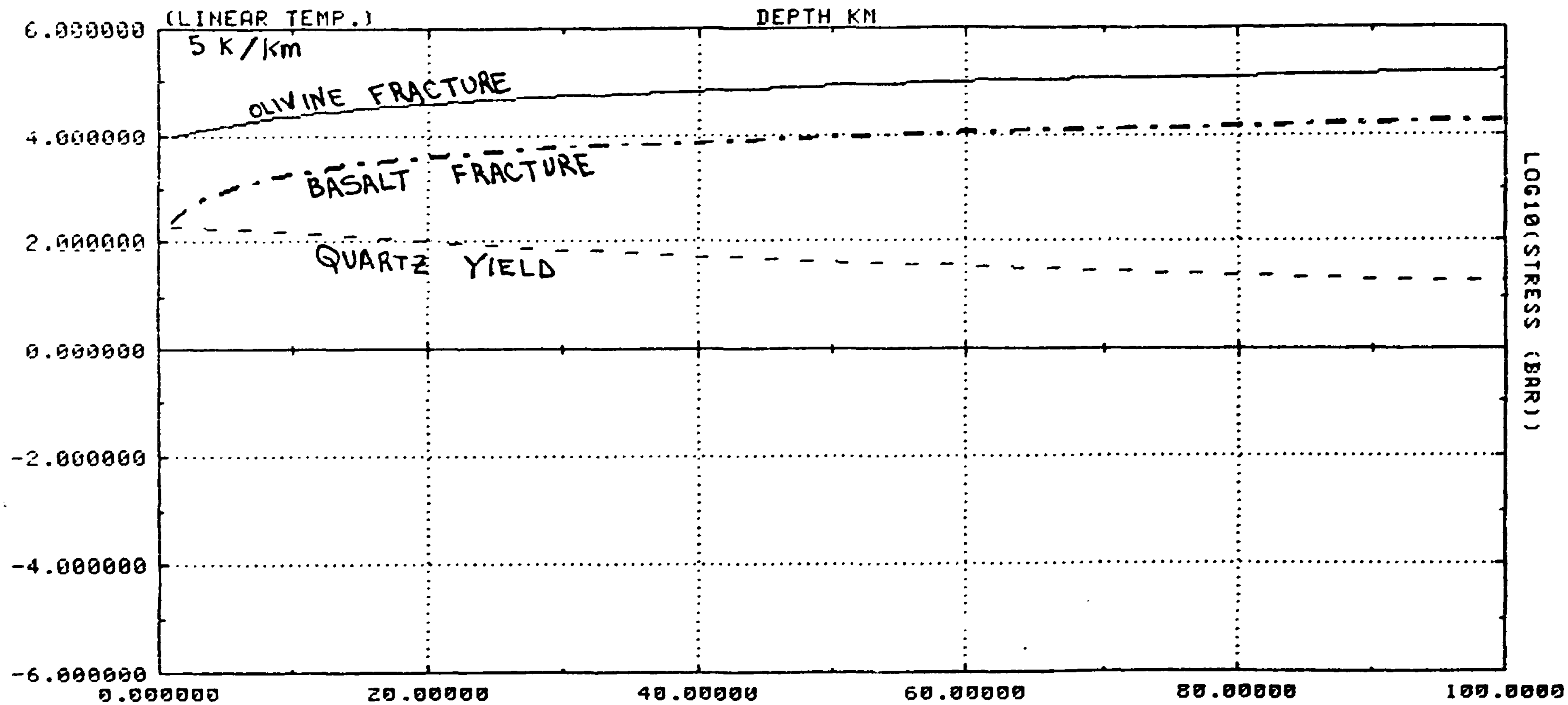

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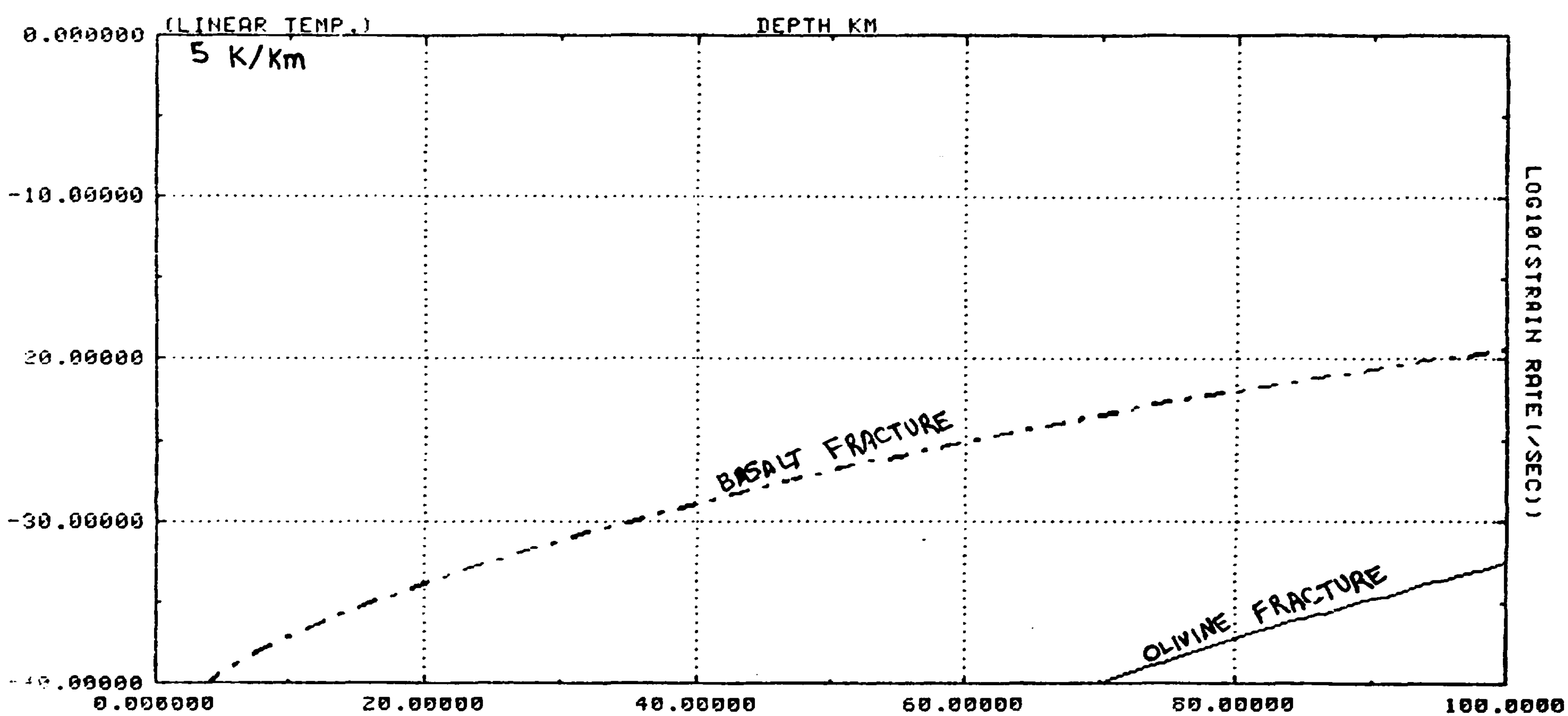

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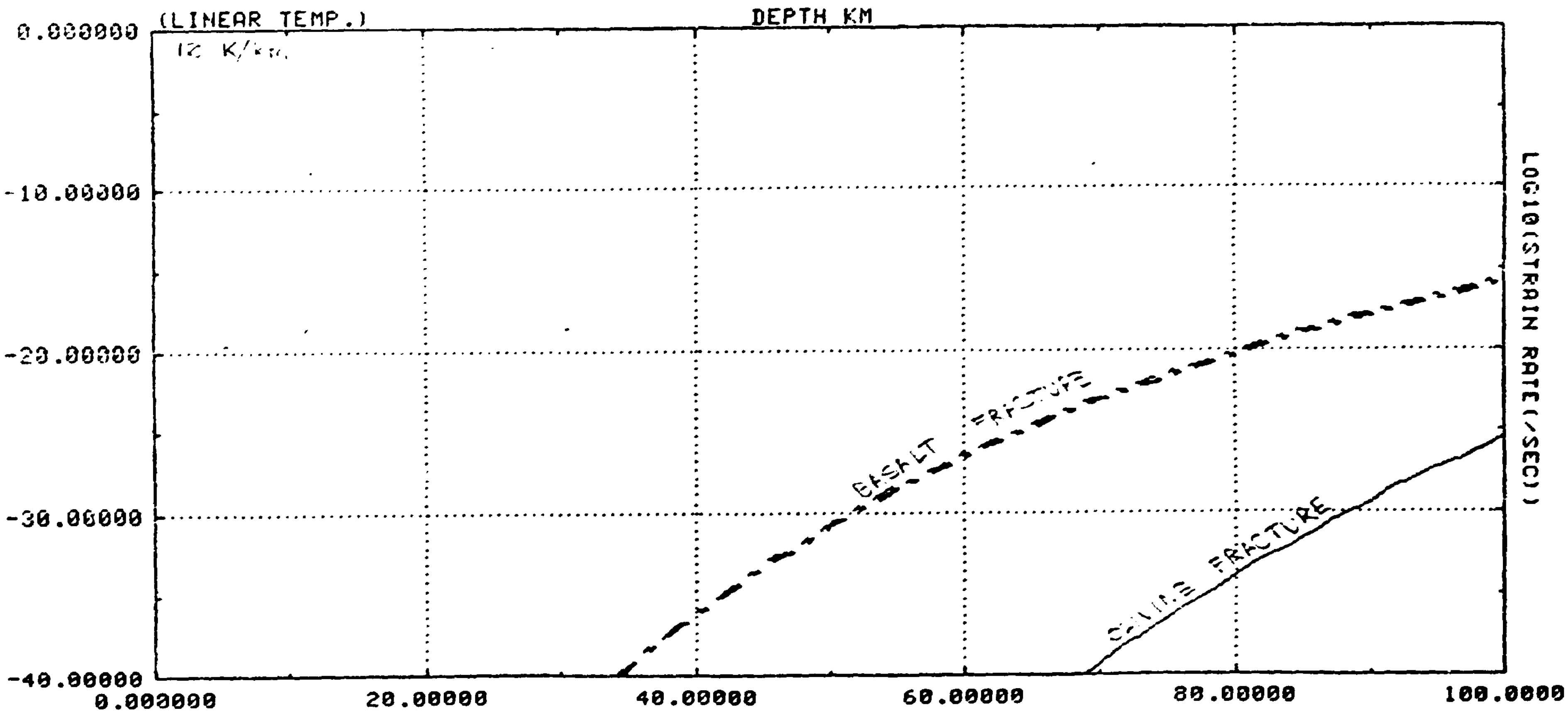

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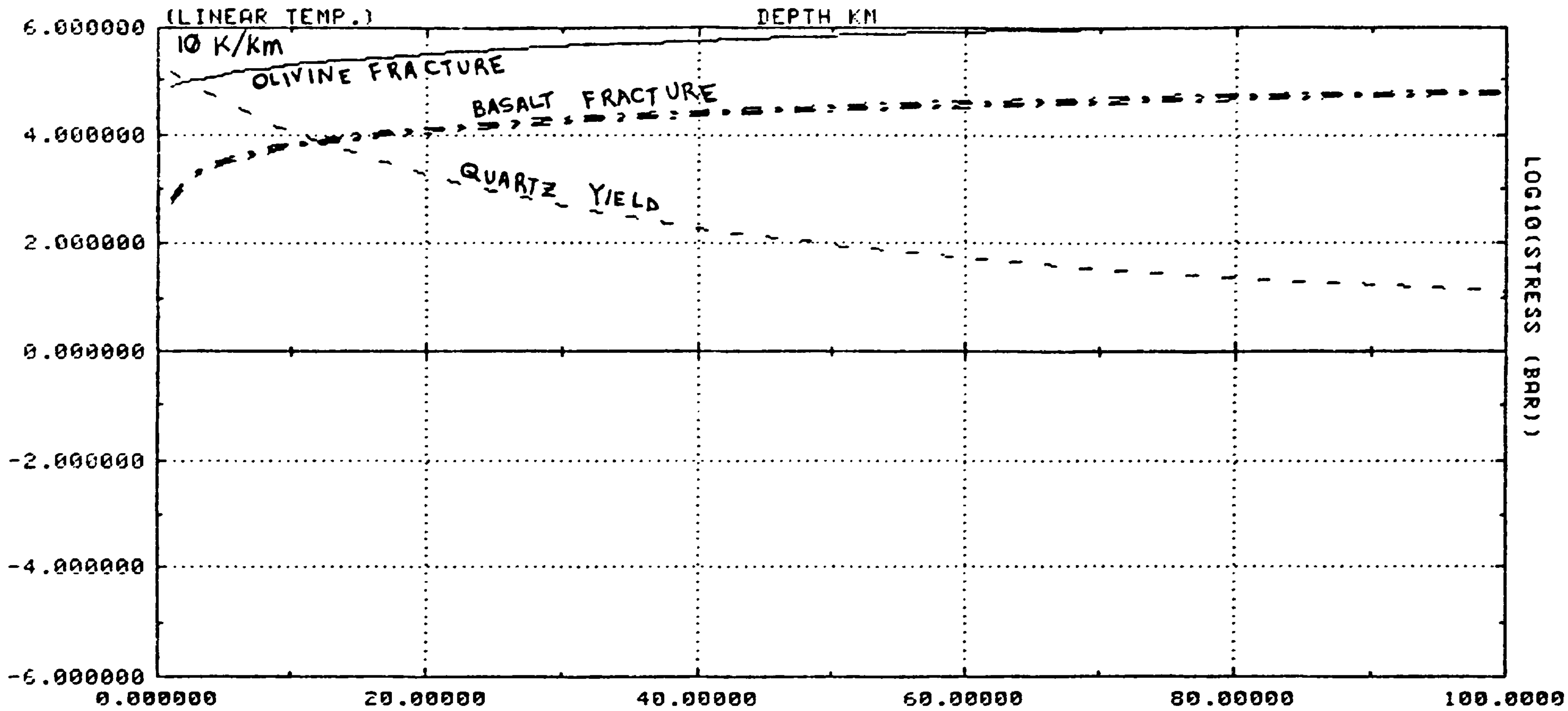

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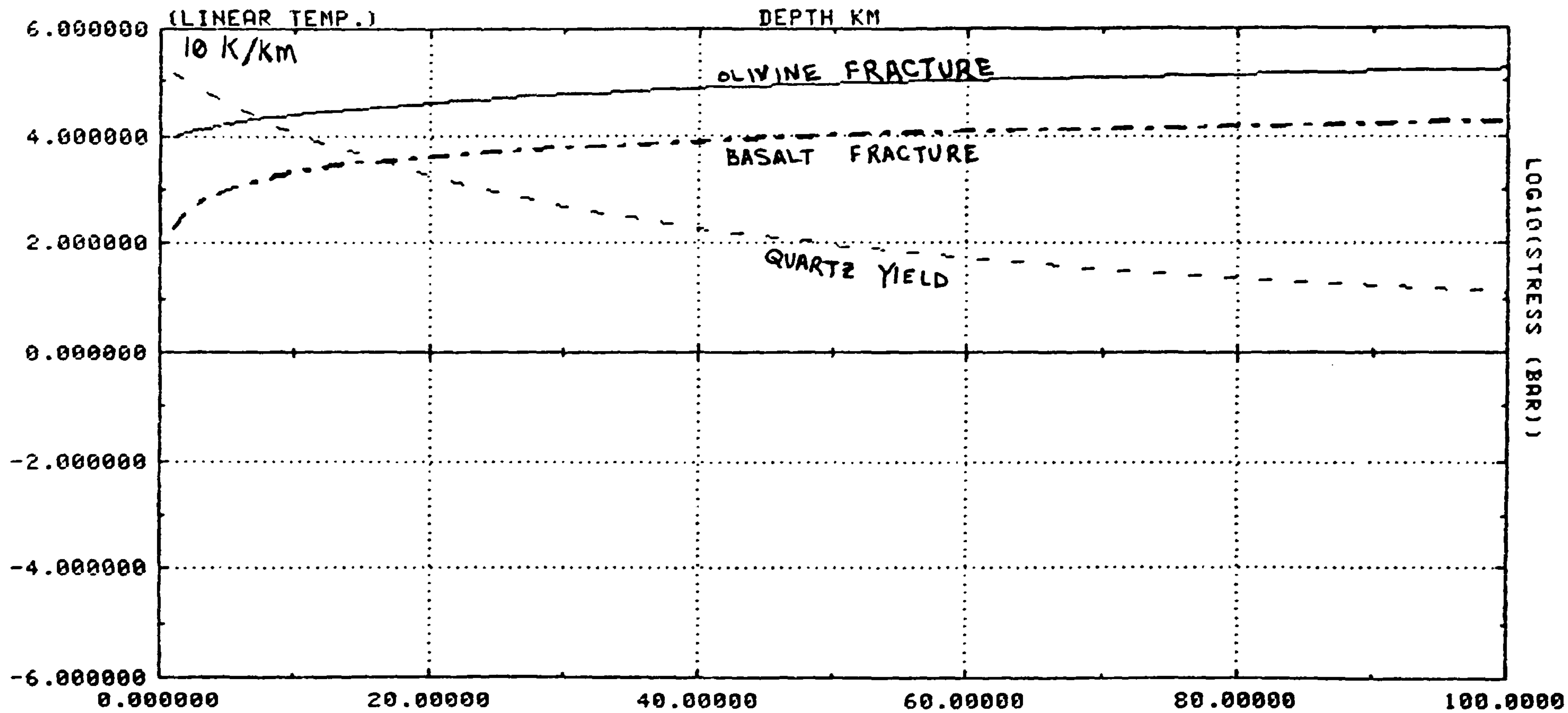

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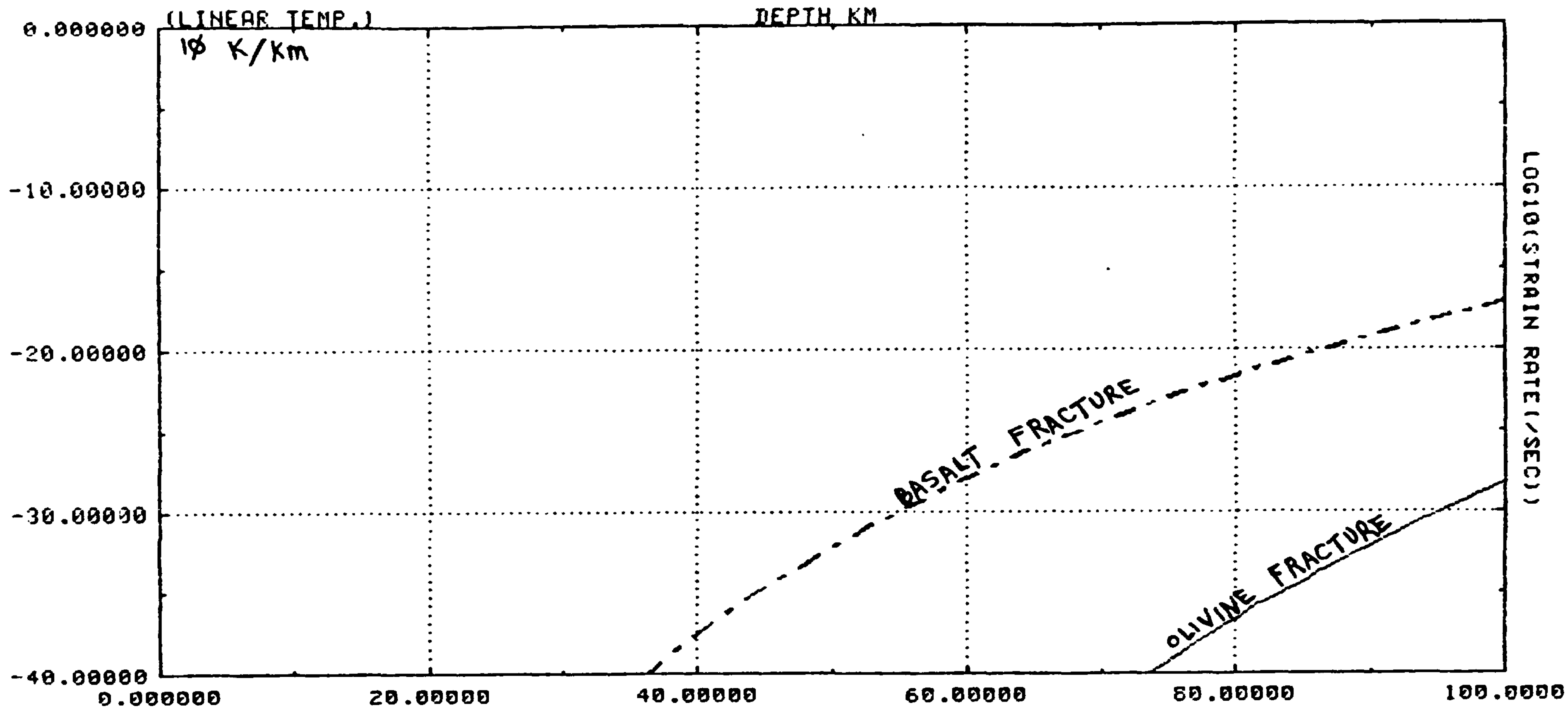

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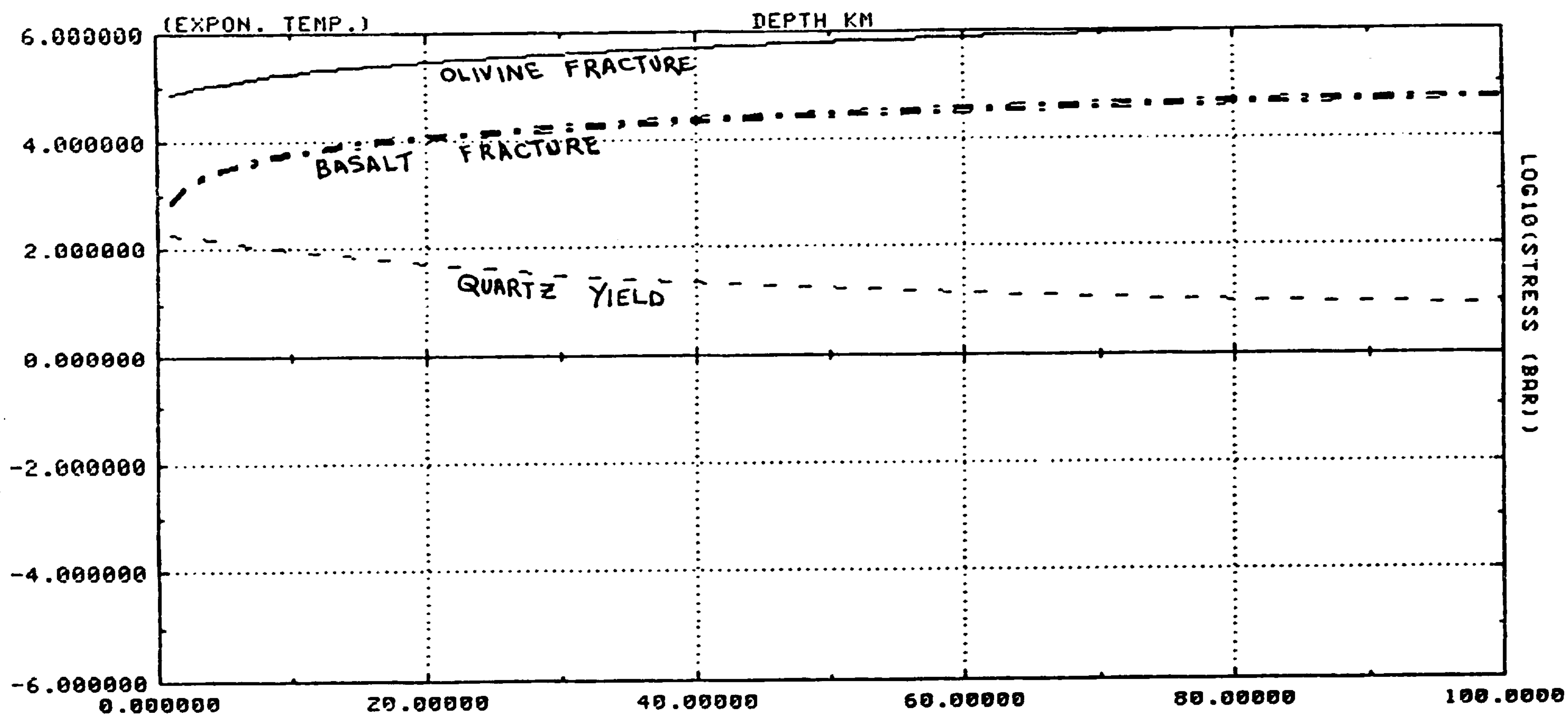

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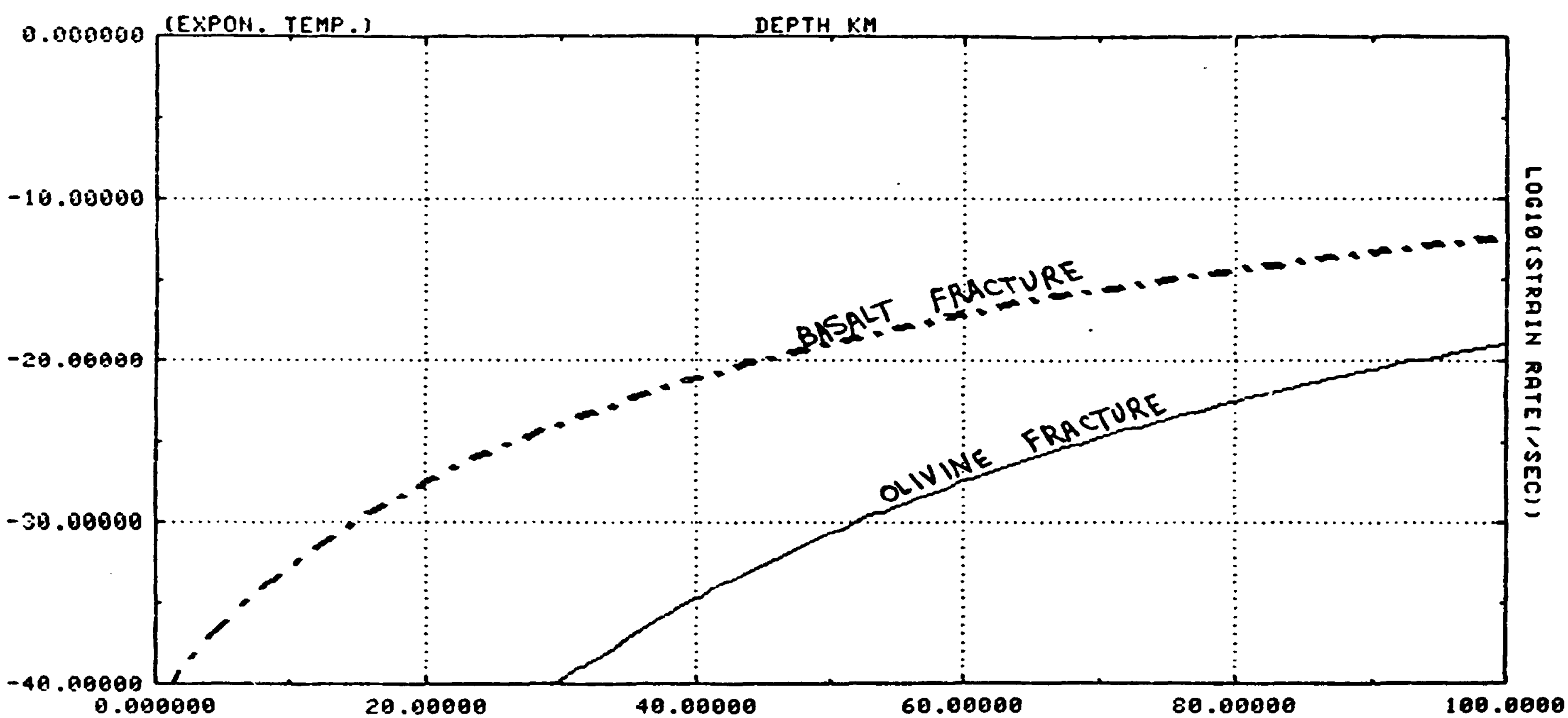

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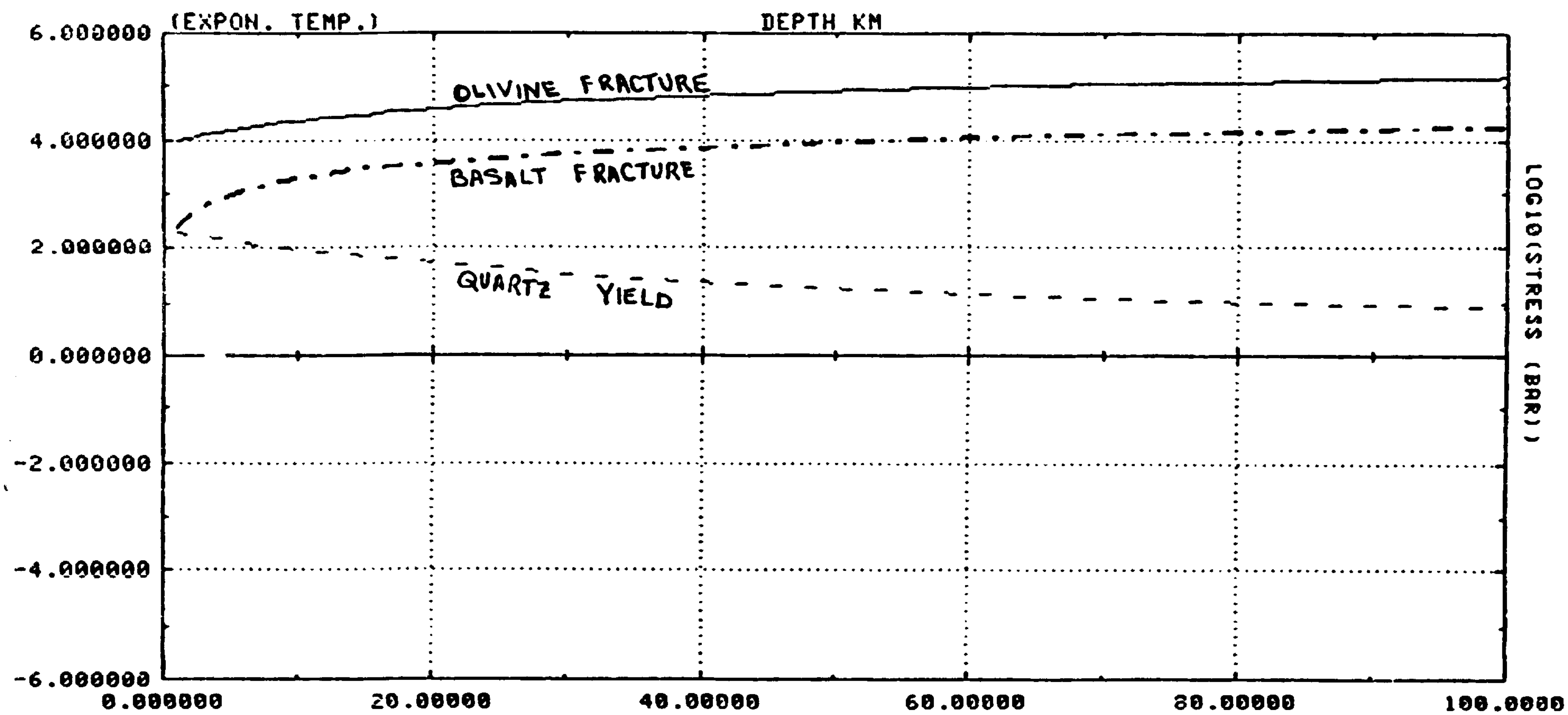

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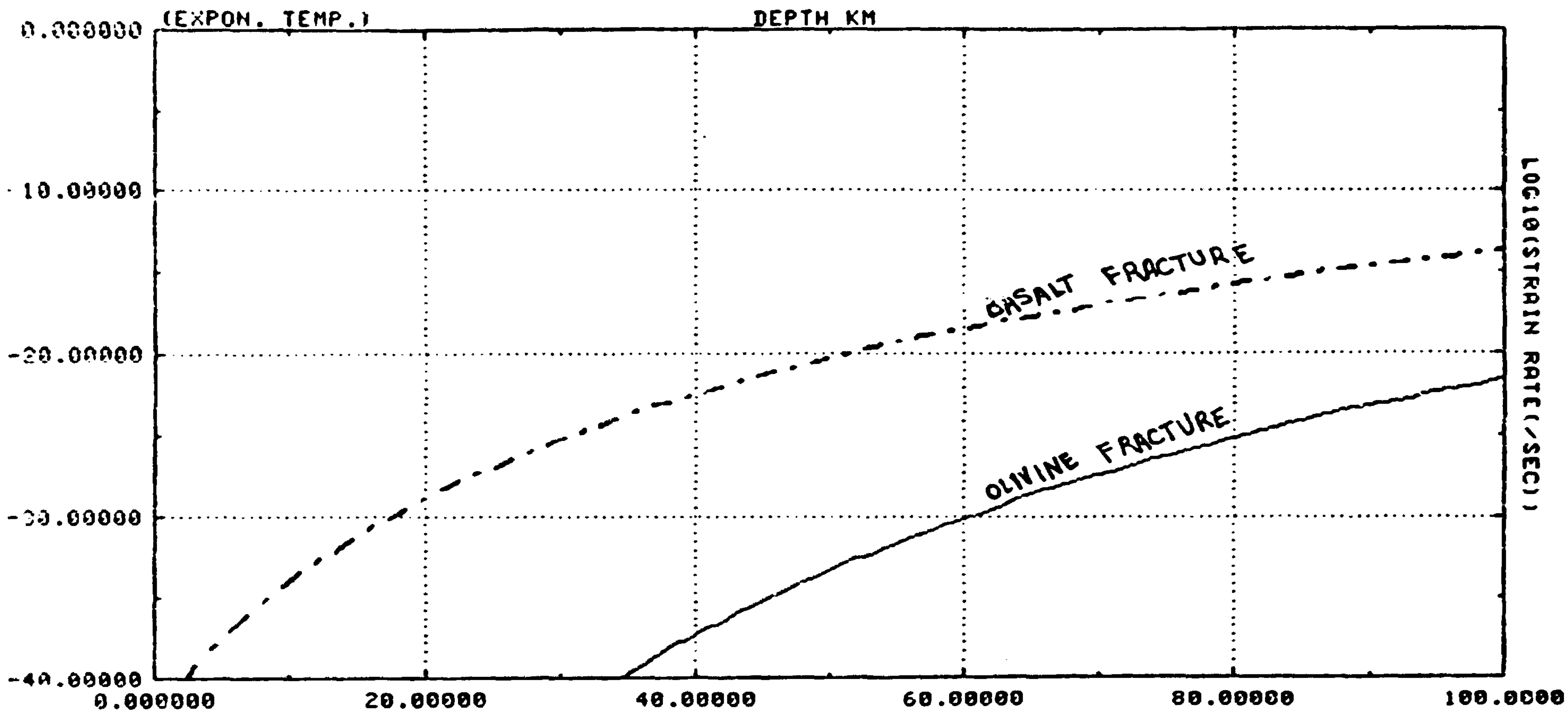

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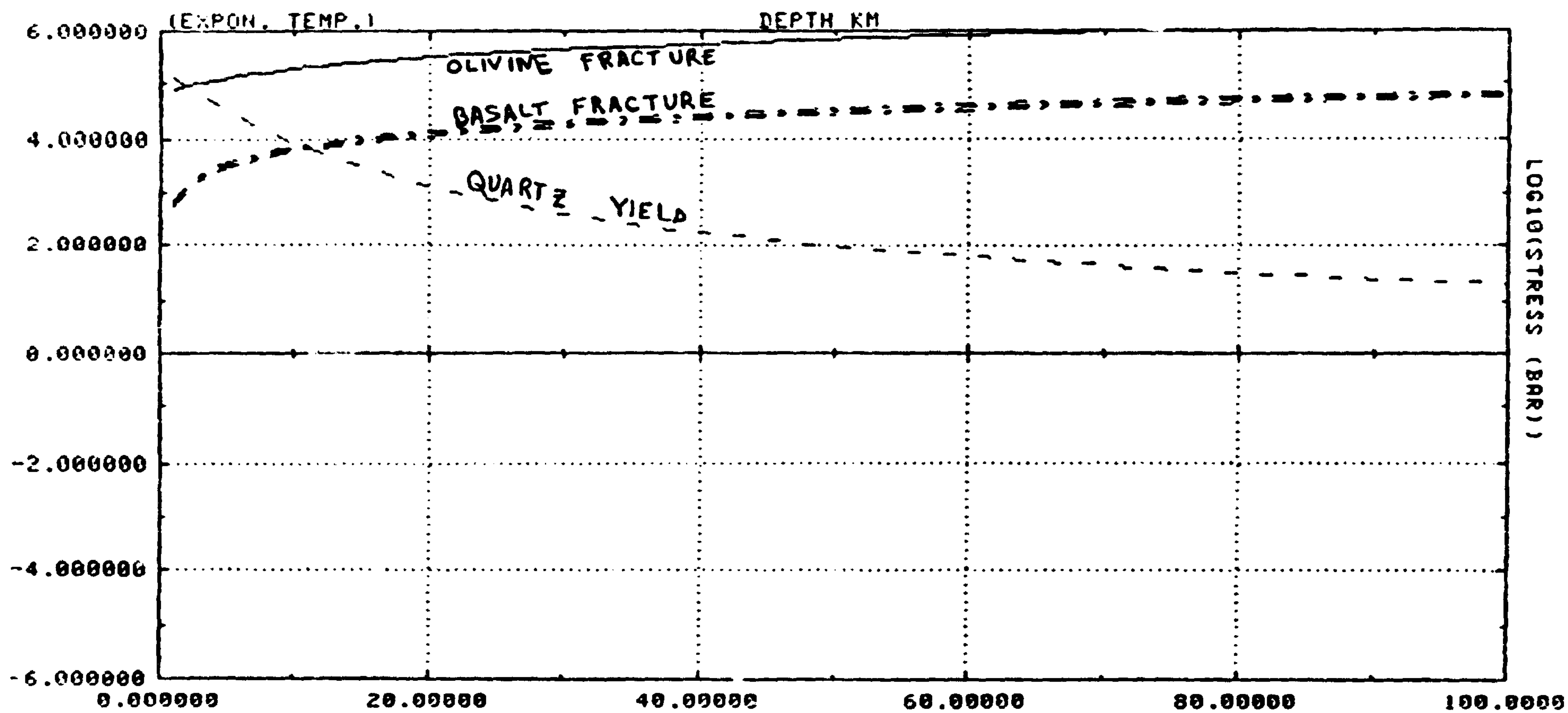

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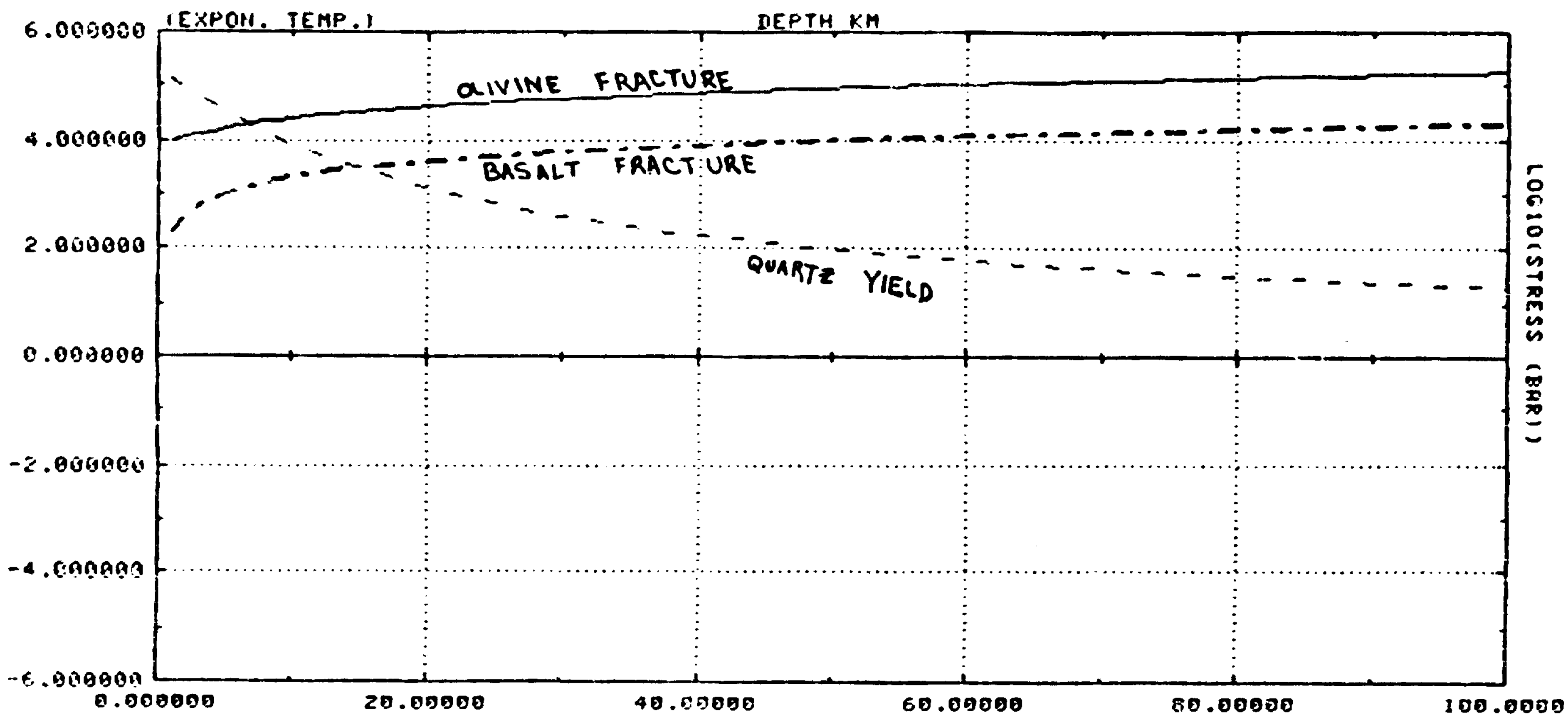

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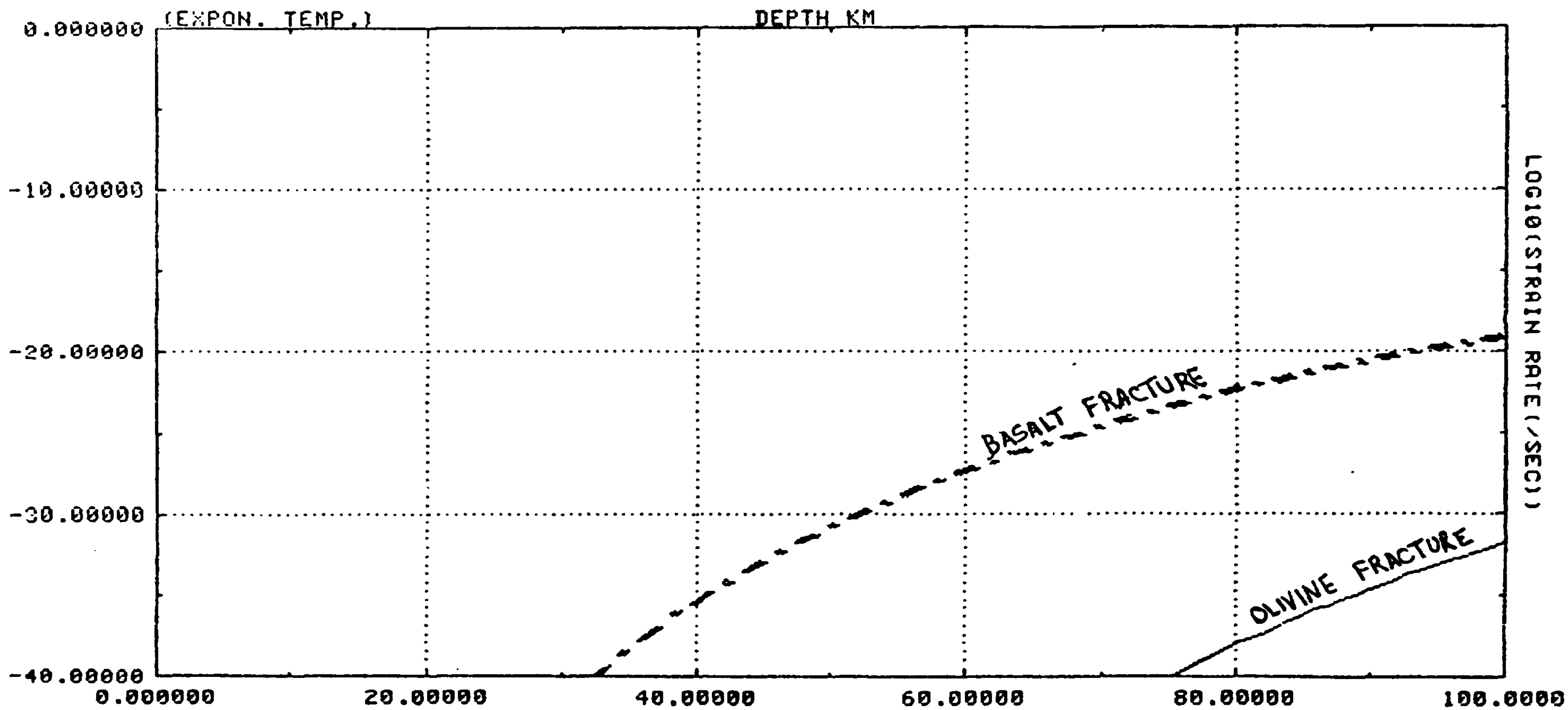

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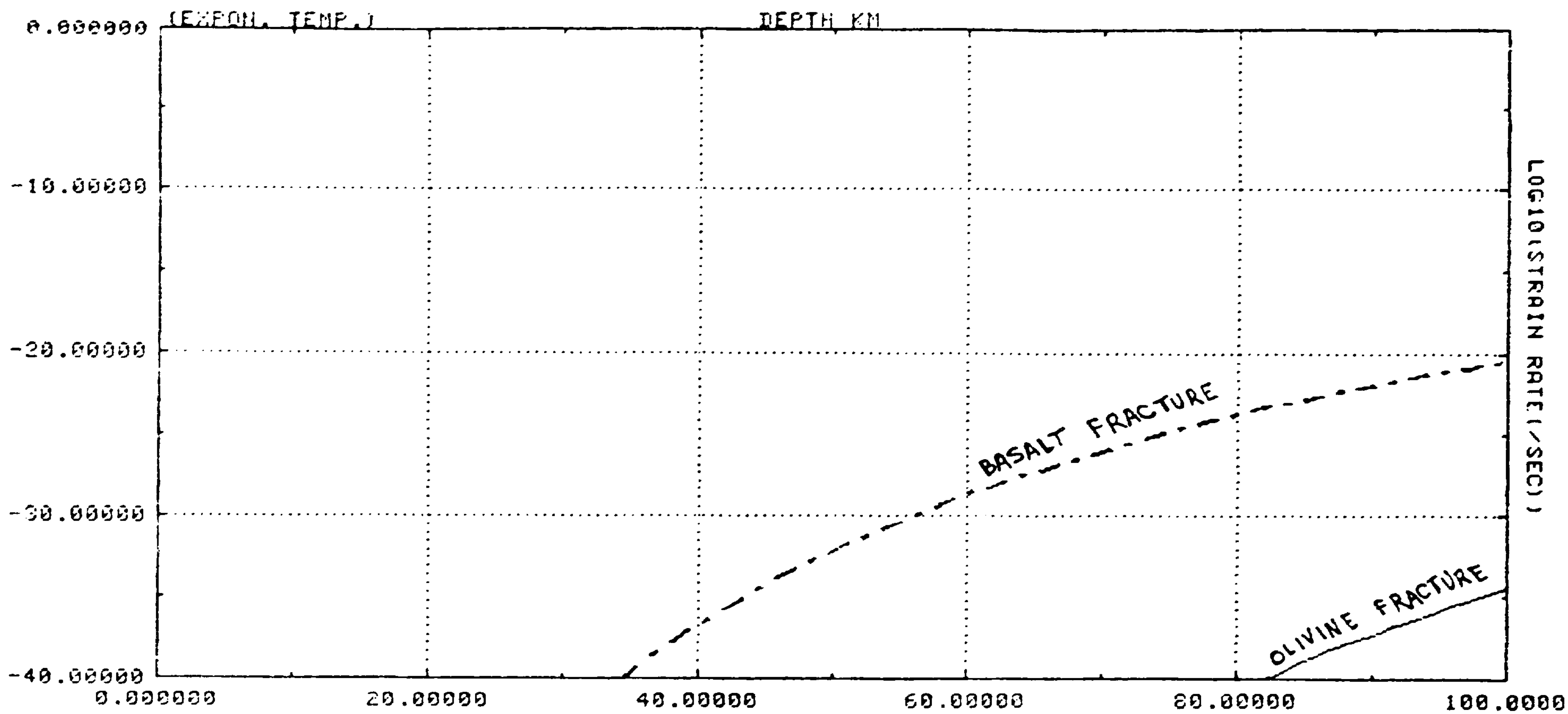

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